

TECHNOLOGY TO IMPROVE AVIATION SAFETY: RECENT EFFORTS AT CLEMSON UNIVERSITY

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Aircraft maintenance and inspection is a complex system consisting of several interrelated human-machine components wherein human plays a key role in ensuring the worthiness of the aircrafts. Considering this fact, it is important to focus on the human in the system. It is critical to deploy strategies that will reduce human error and improve human performance. One area in need of improvement is inspection. It has been proven that there are vast differences in inspection performance between experienced and novice inspectors. One proven technique for improving inspection performance is training. In response to this need, the paper outlines recent effort at Clemson University on the use of advanced technology ranging from computer based simulations to virtual reality technology to upgrade the inspection skills, reduce human error and eventually improve aviation safety.

Introduction

Sound aircraft inspection and maintenance are an essential part of safe and reliable air transportation. Aircraft inspection is a complex system with many interrelated human and machine components (Drury and Gramopadhye, 1990; Drury, 1991). In the aircraft industry, 90% of all aircraft inspection is visual in nature conducted by human inspectors. Thus it is critical that a high level of inspection performance is achieved but human inspection is not 100% reliable (Chin, 1988; Drury, 1992).

Training has been identified as the primary intervention strategy to improve the quality and reliability of aircraft inspection. In the aircraft industry, on-the-job training (OJT) is the predominant form of inspection training but this may not be the best method of instruction (Latorella et al., 1992). For example, OJT does not allow for timely and frequent feedback and it does not offer comprehensive exposure to defect scenarios, as the trainee can only see the defects present in the aircraft being inspected.

The use of offline technology has been studied to overcome these problems (Gramopadhye et al. 2003). One of the most viable approaches in the aircraft maintenance environment is computer-based training that offers several advantages over traditional training approaches, which is more efficient while facilitating standardization and supporting distance learning at the same time. This paper discusses various developments in using multimedia technology to provide offline training for aircraft inspection.

Computer Technology for Training

As computer technology is becoming cheaper, an increasing trend towards the application of advanced technology to training can be foreseen. In visual inspection training, the earliest effort using off-line inspection training was by Czaja and Drury (1981), who used keyboard characters to develop a computer

simulation of a visual inspection task. Low fidelity inspection simulators with computer-generated images to develop off-line inspection training programs have been used by Latorella et al (1992) and Gramopadhye, Drury and Sharit (1994) for inspection tasks. Drury and Chi-Fen (1995) studied human performance using a high fidelity computer simulation of a PCB inspection task. Kundel et al. (1990) have applied advanced technology to the inspection of X-rays for medical practice.

In the past decade, computer-based simulators have been used for aircraft inspection training (Latorella et al., 1992; Gramopadhye et al., 1994; Gramopadhye et al., 1998; Blackmon et al., 1996 Nickles et al., 2001). A recent example is the Automated System of Self Inspection for Specialized Training (ASSIST). ASSIST is a training program developed using task analytic methodology and featuring a PC-based aircraft inspection simulator where an image of a task an airframe is presented to the user for inspection (Gramopadhye et al., 2000). The system has a user-friendly interface and capitalizes on graphical user interface technologies and human factor research on information presentation, ease of use, and information utilization.

The results of a follow-up study conducted to evaluate the usefulness and transfer effects of ASSIST were encouraging as to the effectiveness of computer-based inspection training, specifically in improving performance indicated by high scores on various usability measures (FAA, 2000; Gramopadhye et al., 2000). The advantages of ASSIST have been seen through usability evaluation, performance evaluation, and post training evaluation. Even though there were some advantages, the simulator is limited by its personal computer (PC) based technology. It uses only two-dimensional section images of airframe structures and does not provide a holistic view of the aircraft cargo bay and hence it lacks realism. Moreover, the inspectors are not immersed in the environment, and, therefore, they do not perceive the same look and feel of conducting an actual inspection.

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To address these limitations, virtual reality (VR) technology has been proposed as a solution. In response a high fidelity virtual reality based inspection simulator has been developed (Duchowski et al., 2000).

Virtual Reality for Training

Virtual reality, described by several researchers (Kalawsky, R.S, 1993; Burdea et al., 1994; Durlach et al., 1995; Heim M., 1998), is most applicably defined as immersive, interactive, multi-sensory, viewer-centered, three dimensional computer-generated environments and the combination of technologies required building them (Cruz- Neira, 1993). As these definitions suggest, creating a virtual environment (VE) requires immersing humans into a world completely generated by a computer. The human user becomes a real participate in the real world, interacting and manipulating virtual objects. Therefore, human performance is one of the most important considerations in defining the requirements for a virtual environment. Abstract values such as ease of use, ease of learning, presence and user comfort become significant during human-computer interaction. For virtual environments presence, the subjective experience of being in one place or environment even when one is physically situated in another (Singer et al., 1996) becomes the most important measure.

The concept of experiencing 'presence', as a normal awareness of attention phenomenon, is based on the interaction between external stimuli and immersion factors. Fully immersed observers perceive that they are interacting directly or remotely with the environment. Thus, presence becomes a subjective sensation or mental manifestation that is not easily amenable to objective physiological definition and measurement, with its strength varying both as a function of individual differences, traits, and abilities and the characteristics of VE. The success of using VR as a tool for training and job aiding, therefore, is highly dependent on the degree of presence experienced by the users of the virtual reality environment. In this essence, it is critical to measures the degree of presence of the VR simulator to support training. If the VR simulator is to be proposed as a solution for off-line training, it is essential that this environment accurately mimic the real world as perceived by the user or trainee. Only then can the effects of training be expected to transfer from the VR environment to the real world.

The experiments conducted at Clemson University using VR have been successful in indicating that there is improvement in the inspector's performance. Analysis of the correlation revealed that the subjects who experienced a sense of involvement in real world experiences also felt involved in the VR experienced. In addition, the subjects who experienced high involvement in the simulator felt that their experiences were as natural as the real world ones. Also, the mental and physical state of the

person and the tendency to avoid distractions while performing a particular task, that is, "being focused", did not affect the performance of the subjects on the assigned inspection task. Figure 1 shows the physical features of the real aircraft cargo bay.



Figure 1: Aft cargo bay of L1011 aircraft

Development of VR Simulator

The development of the VR environment was based on a detailed task analytic methodology (FAA, 1991; Nickles et al., 2001). Data on aircraft inspection activity were collected through observation, interviewing, shadowing, and digital data capturing techniques. More detail on the task description and task analytic methodology can be found in Nickles et al. (2001). More detail on the task description and task analytical methodology can be found in Duchowski et al.(2001).

Various scenarios were developed which were representative of those would occur in the real world environment (Figure 2). A library of defects was developed occurring at various severity and locations. The following defects were modeled: corrosion, crack, crease, abrasion, hole and broken conduits. By manipulating the type, severity, location and defect mix; experimenters can now create airframe structures that can be used for running controlled studies.



Figure 2: Virtual reality model of aircraft cargo bay

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The principal hardware component is a head mounted display (HMD) integrated with a binocular eye tracker, jointly built by Virtual Research and ISCAN (Figure 3). Ascension Technology Corporation's Flock of Birds (FOB) tracking system is used for rendering the virtual scenario with respect to the participant's position and movements. For the purpose of selection and pointing in the virtual environment, a hand held mouse with six degrees of freedom is used. The simulator is launched on a 1.5GHz dual Pentium 4 processor Dell personal computer with an NVidia GeForce4 TI4600 graphics card, running the Red Hat Linux 8 operating system.



Figure 3: Head Mounted Display and 3-D mouse

The software component of this simulator consists of two programs, Inspector and Vspec. The Inspector program displays the virtual reality scenario to the participants and at the same time records the participant's eye movements, while Vspec (Figure 4) is used to analyze the data collected by Inspector.

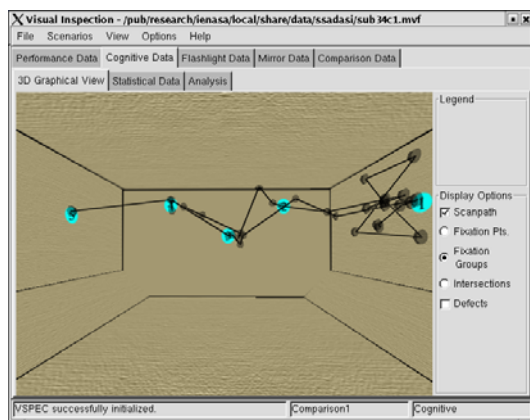


Figure 4: Screen shot of Vspec showing eye movements

Descriptions of Studies

The following studies describe some of the past and ongoing research using the VR simulator at Clemson University.

In this study, the degree of presence of the VR simulator was measured by subjective evaluation (Vora et.al, 2001). Subjects were taken to the hangar floor and shown the real aft cargo bin of a wide-bodied aircraft. They were then taken to the VR lab at Clemson University and randomly immersed in five scenarios with and without defects after familiarization training. The task involved walking through the environment, identifying defects present if any and using the 3D mouse to click on the defect. The subjects were then asked to complete the Presence Questionnaire based on a 7-point likert scale with anchor at the midpoint (Witmer et al., 1998).

The results point towards a high level of presence experienced by the subjects. On issues like the visual aspects of the environment, sense of objects, anticipating the response of the system, surveying, experience in the VR environment contributed to the high sense of involvement. The VR system scored significantly high on the issues related to the concentration on the assigned task by the subjects and also on the adjustment to the control devices, relating to a high level of realism, which is a testament to the high quality of the interface. Subjects indicated that the experiences with the VR environment were consistent with the real world experiences.

Feedback information has had consistently positive results in all fields of human performance (Gramopadhye et al., 1997), if given in a timely and appropriate manner. Wiener (1975) has reviewed feedback in training for inspection vigilance and has found it universally beneficial. Traditional feedback provided to the inspector has been performance feedback (speed and accuracy). Another form of feedback is information on the inspection process (search strategies, eye-movements data).

The primary objective of another study conducted was to evaluate the effectiveness of alternate feedback strategies on visual search performance: speed, accuracy, and search strategies. Subjects were immersed in the VR simulator and asked to perform an inspection task. Performance measures (search time, stopping time, defect detection accuracy and incremental stopping time) and process measures (number of fixations, percentage area covered and fixation times) were recorded and analyzed. This information was then provided to the subject as feedback training which was followed by an inspection task. The results showed improvement in inspection performance by improving speed and accuracy after training.

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Subjects in the performance group, after receiving outcome information during the training session showed improved inspection performance by reducing search time and stopping time, and increasing detection accuracy. This reinforces the finding from other studies (Czaja and Drury, 1981; Micalizzi and Goldberg, 1989) that outcome or performance feedback enhances performance.

The cognitive feedback group received task information in visual and statistical form. This change in search strategy helped subjects in the cognitive feedback group to reduce the search time but increased the stopping time and there was a considerable improvement in the accuracy with an increase in detection accuracy. Higher stopping times and a larger number of fixations showed that to compensate for the lack of performance feedback information and its potential for influencing the effectiveness and efficiency of their search strategy. Without the performance feedback, subjects were not completely able to realize the impact of strategy changes on inspection performance, thus degradation in search efficiency with higher stopping times improved search accuracy.

The use of prior information (feedforward) is known to affect inspection performance (McKernan, 1989). This information can consist of knowledge about defect characteristics (types, severity/criticality, and location) and the probability of these defects. Although several studies have been conducted that demonstrate the usefulness of feedforward as a training strategy there are certain research issues that need to be addressed. These issues include: what format should feedforward information be presented in, when should feedforward information be presented, and how much feedforward information should be presented. Ongoing studies intend to evaluate the effect of feedforward information in a simulated 3-dimensional aircraft inspection environment. A virtual aircraft cargo bay in which inspectors must locate and identify various types of defects is the environment used.

It has been shown that trained inspectors employ a more effective inspection strategy than novice inspectors (Schoonard et al. 1973). Using eye tracking equipment, the point of regard data of an expert inspector can be recorded while performing an inspection task. The analysis of this data allows the characterization of the expert inspector's visual search strategy. The expert inspector's search strategy information can then be provided as feedforward training to novice inspectors to accelerate their adoption of a more effective search strategy. This study deals with the development of a training medium to provide the search strategy information of an expert inspector to novice inspectors. The effect of this training on the novice inspector's visual search process and performance will be experimentally evaluated. An initial study was carried out to examine display techniques that

might be used to present the feedforward information (Sadasivan et al., 2003).

Research in the use of job-aiding tools (flashlight and mirror) in conjunction with feedforward information is also underway.

Discussion and Conclusions

In this paper we have discussed some of the research conducted at Clemson University in using advanced multimedia technologies with an aim of improving aviation safety. ASSIST is stand alone training system that only requires a PC. The VR environment allows researchers to conduct off-line controlled studies, facilitating the collection of performance (e.g., speed and accuracy) and process measures data (e.g., eye-movements strategies). The outcome of this research can be used to understand different aspects of the aircraft inspection process and factors affecting the inspection performance. Earlier studies have shown good transfer effects between virtual environments and real-world environments (Vora et al., 2001) in aircraft inspection. The results of these studies will throw new light in the use of feedback and feedforward in improving inspection performance, which will ultimately improve safety. Using the VR simulator, we will be able to provide novice inspectors with a variety of training techniques and scenarios, thereby bringing their inspection performance closer to that of experienced inspectors in a shorter time span.

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